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Systematic review

Systematic review of the role of a belly board device in radiotherapy delivery in patients with pelvic malignancies

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ABSTRACT

Purpose: This review analyses the literature concerning the influence of the patient position (supine, prone and prone on a belly board device (BB) on the irradiated small-bowel-volume (SB-V)) and the resulting morbidity of radiation therapy (RT) in pelvic malignancies.
Methods: A literature search was performed in MEDLINE, web of science and Scopus.
Results: Forty-six full papers were found, of which 33 met the eligibility criteria. Fifteen articles focussed on the irradiated SB-V using dose volume histograms (DVHs). Twenty-seven articles studied the patient setup in different patient positions.
This review showed that a prone treatment position can result in a lower irradiated SB-V as compared to a supine position, but a more significant reduction of the SB-V can be reached by the additional use of a BB in prone position, for both 3D-CRT and IMRT treatment plans. This reduction of the irradiated SB-V might result in a reduced GI-morbidity. The patient position did not influence the required PTV margins for prostate and rectum.
Conclusions: The irradiated SB-V can be maximally reduced by the use of a prone treatment position combined with a BB for both 3D-CRT and IMRT, which might individually result in a reduction of GI-morbidity.

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In radiation oncology new high precision techniques as intensity modulated radiotherapy (IMRT) [1–3] and adaptive radiotherapy (ART) [4–7] get incorporated in daily practise and lead to a better sparing of critical organs. Despite these new techniques, dose escalation in the irradiation of pelvic malignancies remains limited by the presence of the small intestine in the irradiated volume and the expected higher incidence of acute and chronic small bowel morbidity. The overall incidence of acute and chronic small bowel complications after pelvic irradiation to a dose of 50 Gy is in the order of 2–9% [8,9]. NTCP modelling studies found the small bowel volume receiving 15 Gy (V15) [10] and 45 Gy (V45) to be the most relevant parameters for gastrointestinal (GI) toxicity [11,12]. The most significant association between gastrointestinal (GI) toxicity and irradiated small bowel volume (SB-V) was found in patient groups receiving concurrent chemotherapy [13]. In series with concurrent chemotherapy, the small bowel complication rate seems doubled and reaches rates as high as 25% [10]. Therefore, SB-sparing is particularly interesting and challenging in this patient population.

Furthermore, reduction of radiation induced GI toxicity is important since surgery might in the future no longer be necessary in certain selected patient groups, if radiation is combined with an early tumour response evaluation using functional imaging [14,15]. But, reducing GI toxicity is not the only aim of SB sparing. Improved SB sparing also permits dose escalation for pelvic irradiation [16], which will consequently allow improvement of the tumour control probability.

Recently, Fiorino et al. [17] and Kavanagh et al. [8] reviewed the risk of SB toxicity after irradiation. They described several studies that identified the quantity of SB-V lying in the treatment volume as a risk factor influencing the SB-morbidity after radiotherapy. The irradiated SB-V can be minimalized by different surgical techniques like clip placement in high risk areas, pelvic reconstruction, reperitonealization of the pelvic floor, placement of an omental sling, retroversion of the uterus or by placing a synthetic prosthesis under the SB (a removable pelvic spacer). The irradiated small bowel volume can also be minimalized by non-surgical radiotherapeutical means, including 3D conformal radiotherapy, intensity modulated radiotherapy (IMRT), adaptive radiotherapy, customized shielding, a shrinking field technique, bladder distention and optimal irradiation position such as supine, prone or by using a belly board (BB).

This review focuses on the value of choosing the ideal treatment position and the use of a belly board device in radiation therapy of pelvic malignancies and its efficacy to minimise the SB-V in the treatment volume. Because of concerns about larger setup inaccu-

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racy in prone position with and without a BB compared to supine position, an overview of the literature analysing this question will be given as well.

Methods

Search strategy and selection criteria

A literature search was performed in MEDLINE, ISI web of Science and Scopus in order to retrieve studies concerning the value of the treatment position and the use of a belly board device in the radiotherapy treatment of pelvic malignancies. The following search terms and synonyms were used: radiotherapy, prone position, supine position, belly board, up down table, small bowel displacement device, vacuum bag. Furthermore, the references in the found papers were screened in order to retrieve additional relevant papers. To be selected for this review, studies had to fulfil to the following eligibility criteria:

(1) comparison of different radiation treatment positions including supine, prone and/or prone on a BB in pelvic irradiation;
(2) evaluation of SB-V with dose volume histograms (DVHs);
(3) a minimal study population of 10 patients.

Articles up to November 2011 were included. Both prospective and retrospective studies were reviewed. Articles in languages other than English, German or French were excluded.

More specifically, the purposes of this review are:

(1) To quantify the SB-V in different treatment positions during 3D-CRT for pelvic malignancies:
  a. comparison supine vs prone position;
  b. comparison supine vs prone on a BB;
  c. comparison prone vs prone on a BB.
(2) To assess the possible advantages of the use of a BB in combination with intensity modulated radiotherapy (IMRT).
(3) To assess the relation between reduction of the volume of irradiated SB and the morbidity of pelvic irradiation.
(4) Patient setup:
  a. To analyse what is known about the optimal BB position in relation to the anatomy of the patient and the treatment fields.
  b. To investigate what is known about the differences in setup accuracy of bony anatomy, pelvic organs and the intra- and interfraction organ motion between supine and prone (with and without BB) patient position.

In this review the abbreviation BB refers to all commercial or in-house developed belly board devices and open table tops. The notation V5, V10, V15, etc. is used for the volume that receives a maximum dose of 5, 10 or 15 Gy, etc., respectively. In several reviewed papers the authors described a relative reduction of the SB-V30/40/50 etc. which can be very large at the high dose areas. For example a reduction of the SB-V50 from 8 to 4 cc corresponds to a relative volume reduction of 50%, however, the absolute volume reduction is only 4 cc. Therefore, we have concentrated on absolute volume differences or relative volume differences with respect to the whole SB-V in this review.

Results

Literature search

Using the literature search described, we were able to identify 46 publications, of which 33 full papers met the eligibility criteria. In Fig. 1 an overview of these papers is given. No review article focusing on the advantages and disadvantages of a BB was found. There were no studies available that provided level I or II evidence. Most studies were prospective or retrospective comparative planning studies. Fifteen articles evaluated the SB-V with DVHs. Twenty-seven studies described the BB positioning or evaluated the setup accuracy of bony anatomy and/or the internal motion of the pelvic organs in prone and supine position. The original study from Nijkamp et al. was excluded from the review because the colon was included in the contouring of the bowel [18].

1 Quantification of SB-V in the treatment volume

1a Comparison supine vs prone position

One study evaluated the irradiated SB-V using dose volume histograms (DVHs). Drzymala et al. [19] evaluated prospectively 19 patients with rectal cancer who received preoperative chemoradiotherapy. A full bladder protocol was used. Each patient was scanned twice; first in prone position, then supine. The bladder volume was significantly higher in supine position: the mean difference was 58 cc ($p < 0.0001$). Comparing SB-V5 and -V10 between the different treatment plans, an additional volume of 141 and 136 cc of the SB ($p < 0.0001$) received 5 and 10 Gy in supine position. There was no significant SB-V-difference in V15–V45.

1b Comparison supine vs prone on a BB (Table 1)

There were four prospective studies comparing the SB-V in supine with the SB-V in prone position using a BB [20–23]. Three studies were retrospective analyses [24–26]. One prospective [20] and two retrospective trials [24,25] studied the use of a BB in combination with IMRT.

All studies, except Bertelrud et al. [23], included also postoperatively treated patients. Two CT-scans per patient were used to compare the SB-V in the two treatment positions by all investigators, except for Beriwal et al. [24]. Beriwal et al. compared

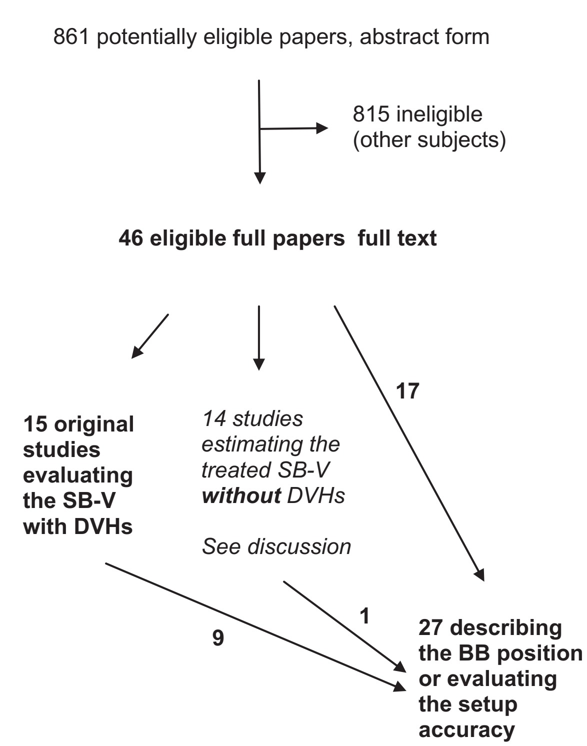

Fig. 1. An overview of the number of papers that were found in the literature search.

Table 1
Overview of eligible original studies comparing the irradiated SB-V between supine and prone position with BB.

Author	*N*	Indication	Treatment	Method	Results
Prospective studies					
Stromberger et al. [20]	10	Cervical ca	Definitive or postop IMRT; 50.4 Gy/1.8 Gy RTCT	Two CTs pp No uniform use of oral contrast No bladder filling instructions	– Significant decrease in SB-V at V20/30/40/45/50.4 prone by 18–2% of the total SB-V or 79–4 cc ($p < 0.05$) – Mean dose of SB was 25.9 vs 30.2 Gy prone with BB vs supine ($p = 0.049$)
Martin et al. [21]	29	Gynaecological ca	Postop irradiation; 43–56 Gy/1.8 Gy With/without RTCT	Two CTs pp Oral contrast (Bladder filling not indicated)	– Significant decrease of SB-V receiving 100%, 95%, 90%, 80% and 70% of prescribed dose prone with BB by 21–45 cc or 4–8% of total SB-V ($p < 0.001$–0.035)
Koelbl et al. [22]	20	Rectal ca	Postop RT; 50.4 Gy/1.8 Gy	Two CTs pp Oral contrast Median bladder-V 180–183 cc	– Significant lower SB-V45.4/V40.3/V30.2/V20.2 prone with a BB ($p < 0.001$) – Significant mean reduction of overlap between SB-V and PTV in prone position with a BB by 32.5 cc ($p < 0.005$) – Lower median dose to the SB prone with BB (15.4 vs 23.9 Gy) ($p < 0.001$)
Bertelrud et al. [23]	30	Pelvic malignancies	Definitive and postop RT	Two CTs pp Oral contrast DB	– Overall SB-V-reduction prone with BB at V40/45/50 of 176, 197 and 108 cc – (*p* values are not indicated) – The same patient group was studied by Shanahan et al. [81]
Retrospective studies					
Beriwal et al. [24]	47	Endometrial ca	Postop IMRT; 45–50 Gy and brachy 10 Gy	One CT pp Oral and iv-contrast Bladder filling not specified	– Not significant reduction of SB-V20/30/40/45 and V50 prone with a BB (ns) – Not significant increase of SB-V10 prone position with a BB (ns) – (SB prone and supine: comparison between different patients!)
Adli et al. [25]	16	Gynaecological ca	Pre-/postop IMRT; 45 Gy	Two CTs pp Oral and iv-contrast Bladder filling not indicated	– Significant reduction of SB-V25–50 prone with BB with limited arc IMRT by 9–3% of the total SB-V ($p = 0.02$–0.003) – Significant reduction of SB-V35–45 prone with BB with extended arc IMRT by 4–3% of the total SB-V ($p = 0.03$–0.04)
Pinkawa et al. [26]	20	Gynecological ca	Definitive and postop RT Brachy in cervical cancer	Two CTs pp Use of contrast not indicated Bladder filling not indicated	– Significant reduction of SB-V receiving 50%, 60% and 90% of the prescribed dose prone with BB in postop RT only ($p < 0.001$) – Significant mean reduction of the SB-V receiving 90% of the prescribed dose in postop RT prone with BB by 13% of the total SB-V ($p < 0.001$)

Abbreviations: BB, belly board; brachy, brachytherapy; Ca, cancer; CT, computer tomography; DB, distended bladder; IMRT, intensity modulated radiotherapy; preop/postop, preoperative/postoperative; pp, per patient; PTV, planning target volume; RT, radiotherapy; RTCT, concurrent radiochemotherapy; SB-V, small bowel volume; SB-V10/20/…, small bowel volume receiving 10/20… Gy.

retrospectively two patient groups who were treated in different positions [24]. In the prospective studies a significant reduction of the irradiated SB-V up to 197 cc at V45 was observed for patients positioned prone on a BB [20–23]. The largest absolute reduction of the irradiated SB-V was predominantly seen in the low dose areas of the treatment volume.

1c Comparison prone vs prone on a BB (Table 2)

There were five prospective studies [27–31] and two retrospective studies [32,33] comparing the SB-V in a prone treatment position with and without the use of a BB. In the prospective studies and one retrospective study a significant average reduction of the SB-V in the treatment volume was observed by 13–167 cc [27–31,33]. In the retrospective study of Hollenhorst et al. [32] in which two different patient groups were compared the difference of the SB-V reduction did not reach the level of significance.

In four studies, two CTs per patient were acquired (with and without BB) [27,30,31,33]. In the studies conducted by Kim et al. [28,29] the investigators conducted four CTs per patient: (1) in prone position with an empty bladder, (2) in prone position using a BB with an empty bladder, (3) in prone position with a full bladder and (4) in prone position on a BB with a full bladder. This made a separate investigation of the influence of the bladder filling possible.

In preoperatively irradiated patients, Kim et al. [28] found that the prone position with a full bladder on a BB resulted in the largest SB-V reduction of 77 cc at the 50% isodose and of 52 cc at the 90% isodose compared to the reference position (prone with an empty bladder; mean bladder volume 120 cc). In the prone position with a distended bladder (mean bladder volume 607 cc) and no BB a reduction of 59 cc at the 50% isodose and 43 cc at the 90% isodose was measured compared to the reference position. Finally, the prone position on a BB with an empty bladder allowed a SB-V reduction of 45 cc at the 50% isodose and a SB-V reduction of 28 cc at the 90% isodose compared to the reference position.

In another study, Kim et al. [29] measured the same parameters in postoperatively irradiated patients. A significant reduction of the irradiated SB-V was confirmed at all dose levels ($p < 0.001$). A mean reduction of the irradiated SB-V was found for the prone position on a BB (empty bladder) of 42 cc, for the prone position with a full bladder of 77 cc and for the prone position on a BB with distended bladder of 99 cc with respect to the prone position without a BB and with empty bladder [29].

In conclusion the combination of a full bladder with the use of a BB shows the best sparing of the SB in pre- and postoperatively irradiated patients. The SB-V reduction that could be achieved was comparable for pre- and postoperatively irradiated patients.

Das et al. [31] also found no significant influence of the therapeutic sequence (surgery/irradiation) on the content of SB-V in the treatment volume. A cranial dislocation of the SB of up to 10 cm was measured using a BB compared to the prone position alone [31].

Table 2
Overview of eligible articles comparing the irradiated SB-V between prone position without and with a BB.

Author	N	Indication	Treatment	Method	Results
Prospective studies					
Kim et al. [27]	20	Rectal ca	IMRT PREop RT; 50 Gy	Two CTs pp Oral contrast Empty bladder (120 cc)	– Significant reduction of the SB-V receiving 20–100% of the prescribed dose prone with BB by 69–13 cc ($p < 0.001$–0.012)
Kim et al. [29]	20	Rectal ca	POSTop RT	Four CTs pp with/without DB Oral contrast Rectumcontrast	Four groups: (I) Empty bladder no BB (reference group) (II) Empty bladder with BB (III) Full bladder no BB (IV) Full bladder with BB – Significant reduction of the irradiated SB-V receiving 10–100% of the prescribed dose in groups II till IV with respect to group I ($p < 0.001$) – Mean SBV-reduction of 42 cc; 77 cc and 99 cc in groups II, III and IV with respect to group I
Kim et al. [28]	20	Rectal ca	PREop RT	Four CTs pp with/without DB Oral contrast	Four groups: (I) Empty bladder no BB (reference group)Empty bladder with BB (II) Full bladder no BB (III) Full bladder with BB – Significant reduction of the irradiated SB-V receiving 10–100% of the prescribed dose in groups II till IV with respect to group I ($p < 0.05$) – Mean SBV-reduction of 16–80 cc; 22–163 cc and 29–167 cc in groups II, III and IV with respect to group I
Huh et al. [30]	10	Cervical ca	Definitive RT 45–50 Gy; brachy 24 Gy 70% RTCT	Two CTs pp Oral contrast Bladder filling not significantly different	– Significant reduction of the irradiated SB-V with BB at all dose levels – Median reduction of SB-V at the prescription dose with BB of 8.6% of the total SB-V ($p = 0.005$)
Das et al. [31]	12	Rectal ca	Pre- and postop RT; 50–62 Gy 10 RTCT	Two CTs pp Oral contrast DB	– Significant reduction of the SB-V at each dose level prone with BB – Average reduction of the SB-V receiving 10–100% of the prescribed dose by 81 cc (184–15 cc) – In nearly 60% patients no SB in the treatment volume receiving > 40% of the prescribed dose, using a BB
Retrospective studies					
Hollenhorst et al. [32]	20	Rectal ca	Pre- and postop RT; 45–54 Gy/1.8 Gy Sometimes RTCT	One CT pp Oral contrast (Bladder filling not indicated)	– No significant volume difference of SB-V (ns). Different patient groups prone and prone with BB – Mean dose reduction to the SB with BB by 7–10% of the prescribed dose (with 3- and 4-field-RT, respectively)
Huh et al. [33]	10	Cervical ca	IMRT Definitive RT; 45–50 Gy, brachy 24 Gy 70% RTCT	Two CTs pp Oral contrast Bladder filling not significantly different	– Significant reduction of SB-V intersecting with PTV by an average of 53 cc ($p < 0.008$) – At all dose levels (10–105% of the prescribed dose) consistent reduction of the SB-V (248–4 cc) in BB-assisted IMRT compared to conventional IMRT without BB. SB-V reduction at 15 and 45 Gy was 210 and 33 cc, respectively

Abbreviations: BB, belly board; brachy, brachytherapy; Ca, cancer; CT, computer tomography; DB, distended bladder; IMRT, intensity modulated radiotherapy; Preop/postop, preoperative/postoperative; pp, per patient; PTV, planning target volume; RT, radiotherapy; RTCT, concurrent radiochemotherapy; SB-V, small bowel volume; SB-V10/20/…, small bowel volume receiving 10/20… Gy.

The value of a BB for target volumes of different pelvic malignancies

All studies included in this review investigated patients with rectal or gynaecological malignancies. These studies were performed in operated and non operated patients. The SB-V could be reduced significantly by the use of a BB in prone position for these patient groups (Tables 1 and 2). However, none of the reviewed papers made a comparison between different types of malignancies.

2 Intensity modulated radiotherapy (IMRT)

There were five studies evaluating the SB-V in different positions using IMRT (including a total of 103 patients) [20,24,25,27,33]. Two prospective studies evaluated a total of 30 patients with cervical and rectal cancer [20,27] and three retrospective studies treated a total of 73 patients with different gynaecological malignancies [24,25,33]. Three studies compared the supine position with the prone position on a BB [20,24,25,27] and two studies compared the prone position with the prone position on a BB [27,33].

2a Comparison of the supine position with the prone position on a BB (IMRT)

In a prospective study published by Stromberger et al. [20], treating all patients with IMRT, a significant decrease of the SB-V20/V30/V40/V45 and V50.4 was found using a BB in prone position ($p < 0.05$), as compared to supine position. There was a reduction of the SB-V by 1.5% (V50.4) to 17.7% (V30) corresponding to 8 and 79 cc, respectively. The mean dose to the SB was 25.9 Gy prone with a BB compared to 30.2 Gy supine ($p = 0.049$).

Also in the retrospective studies by Beriwal et al. [24] and Adli et al. [25] a decreased high dose SB-V was found for patients treated prone on a BB; the differences (3–9%) were though only significant in the study of Adli et al. The differences were larger for IMRT plans with a limited arc technique (180° arc) as compared to an extended arc technique (340° arc), because the irradiated SB-V was smaller with the extended arc technique [25]. However, for the SB-V10 Adli et al. found an increase in prone position on a BB (14%).

2b Comparison of the prone position with the prone position on a BB (IMRT)

In the prospective study by Kim et al. [27], a mean reduction of the SB-V of 13–69 cc at dose levels 20–100% ($p < 0.05$) was found using a BB. In this study they used an empty bladder protocol. Huh et al. [33] measured a significant reduction of the SB-V intersecting with the PTV in prone position with a BB of on average of 53 cc and a reduction of the SB-V receiving 10–105% of the prescribed dose by 248–4 cc.

With BB-assisted IMRT a further reduction of the SB-V is possible compared to the use of IMRT alone [20,24,25,27,33]. However, the benefit of a BB in combination with IMRT was smaller or absent in low dose areas (<10% of the prescribed dose) in some studies.

3 Morbidity

Toxicity was scored in only a few of the above mentioned studies. However, in these studies the patients were all treated prone on a BB, since this was considered the ideal position concerning the SB-sparing. Koelbl et al. [22] calculated a median NTCP and found a significant reduction of the probability of developing morbidity using a BB. With the algorithm of Lyman they calculated an NTCP value for acute (α/β = 10 Gy) and late (α/β = 2.5 Gy) SB-toxicity (TD50 according to Emami) in supine position of 3.38 and 2.39, and for prone position on a BB a value of 1.05, and 0.75, respectively ($p < 0.001$). With the model of Kutcher they found median NTCP values for acute and late effects of 4.04 and 2.86 for the supine and 1.28 and 0.86 for the prone position, respectively ($p < 0.001$).

4 Patient setup

4a Optimal position of the BB in relation to the patient and the treatment fields

Koelbl et al. [34] and Lee et al. [35] compared three different BB-positions. Koelbl et al. used a BB aperture with a diameter of 35 cm, while the lower end of the BB aperture was placed at the lumbosacral joint, the sacro-iliac joint and the symphysis, resulting in 433 cc, 640 cc and 862 cc of the SB-V situated within the longitudinal extension of the treatment volume, respectively. The most optimal displacement of the SB out of the planning target volume (PTV) was found with the caudal end of the BB-opening located in the most cranial position. Lee et al. [35] used a BB-opening of 25×25 cm^2 and evaluated the SB-V with the lower end of the BB aperture in the same three positions as described by Koelbl et al. They found corresponding results for SB-V10 and 20. The irradiated SB-V receiving 30% or more of the prescribed dose did not vary significantly while changing the position of the BB-opening.

4b Setup accuracy

In Table 3 an overview of the literature concerning the setup accuracy in supine and prone (with and without BB) position is given. Only three papers compared the setup accuracy of the bony anatomy with and without a BB [36–38]. Italia et al. [36] found no significant differences between the prone position using a BB and an immobilisation cast in institute A and the supine position without a BB or another immobilisation in institute B. Only in the superior inferior (SI) direction they found a larger percentage of patients with an average setup error > 5 mm (23% vs 11% supine) and a larger random setup error (1 SD = 4.2 mm vs 1.8 mm supine) in institute A. Siddiqui et al. [30] found larger residual setup errors using an off-line correction protocol (3D vector length 5.4 mm supine and 5.0 mm prone with BB) due to larger random errors in the supine position as compared to prone position on a BB. Allal et al. [37] found significantly larger average positioning errors for patients treated in prone position using a BB as compared to prone without a BB (up to 4.5 mm with BB and 1.8 mm without BB in the anterior posterior (AP) direction).

The positioning accuracy of the bony anatomy in prone and supine position was investigated in the papers of Greer et al. [39] and Weber et al. [40]. Greer et al. found larger mean (5.2 vs 3.3 mm), random (3.3 vs 2.3 mm) and systematic (4.5 vs 3.7 mm) position deviations in the AP direction in prone position if tattoo alignment was used. If the patients were aligned with a fixed height method they did not find significant differences. Weber et al. did not find significant differences in the mean position deviation and the random variation. They only found larger systematic errors in the prone position with a maximum difference of 4.1 vs 2.2 mm in SI direction.

A comparison between prone and supine position was made for the prostate in ten papers [41–50] and for the rectum in a paper by Nijkamp et al. [51]. Four papers [42,43,46,50] described a larger intrafraction prostate motion in the prone position, especially in combination with immobilisation casts (0.9–5.1 mm prone vs 0.1–0.3 mm supine due to breathing motion). Two papers [44,45] found no significant difference in intrafraction prostate motion between the prone and supine position. Malone et al. [41] found larger respiratory motion in the prone position if immobilisation was used. However, this difference was absent for patients without immobilisation. For the interfraction prostate motion, only small differences were observed between prone and supine position. Furthermore the interfraction shape variation of the mesorectum was comparable in prone and supine position [51].

Stroom et al. [52] compared the internal prostate motion and the required margins for the planning target volume (PTV) for the supine position and the prone position on a BB. They found similar PTV margins of 1 cm in AP and SI direction and 0.5 cm in the lateral direction for both patient positions. Liu et al. [49] state that 0.5 cm margins are appropriate for the prostate in both supine and prone position if soft tissue alignment is used. Nijkamp et al. [51] investigated PTV margins required for the rectum in prone and supine position after online setup correction based on bony anatomy. They found comparable margins for prone and supine position but found differences between male and female patients (up to 1.7 and 2.3 cm for male and female patients in the prone and up to 1.9 and 2.4 cm for male and female patients in the supine position).

Discussion

Comparing the supine with the prone treatment position (without a BB) a reduction of the SB-V is probable in prone position [19]. This was also demonstrated by other authors [53–57]. However, in these papers the SB-V was evaluated with orthogonal radiographs instead of DVHs and therefore, they were not included in this review. A larger reduction of the SB-V can be obtained by the additional use of a BB in prone position compared to both supine [20–26] and prone position alone [27–33]. In the prospective studies the SB-V reduction by a BB compared to prone position alone was 13–167 cc [27–31]. This was confirmed in other studies that were not included in this review because these studies evaluated the SB-V with orthogonal radiographs instead of DVHs or included too few patients [56,58–66].

IMRT has shown to reduce the SB-V receiving the prescribed dose in pelvic RT by 50% compared to 3DCRT [11,67,68]. Using BB-assisted IMRT a further reduction of the SB-V is observed [20,24,25,27,33]. The benefit of a BB in combination with IMRT was smaller or even absent in very low dose areas (<10 Gy). This finding can be expected as IMRT is known to result in larger areas irradiated with low doses. The clinical significance of these very

Table 3
Overview of papers describing the setup errors of the bony anatomy and internal motion of pelvic organs in prone (with and without BB) and supine position.

Paper	Patient position comparison	No. of patients	Method	Correction protocol used	Intra or interfraction motion	Setup error of	Results
Italia et al. [36]	Prone with BB and immobilisation in institute A vs supine in institute B	30 prone and 22 supine	Portal films	No	Inter	Bony anatomy	Only in SI direction: a larger mean setup error (23% of patients > 5 mm vs 11%) and a larger random error (1 SD: 4.2 mm vs 1.8 mm) for the prone position with BB
Allal et al. [37]	Prone with BB vs prone without BB	14 prone with BB and 9 prone without BB	Portal films	No	Inter	Bony anatomy	Significantly larger average positioning errors for patients treated prone on a BB compared to prone without BB. Largest differences in the AP direction (4.5 vs 1.8 mm)
Siddiqui et al. [38]	Prone with BB vs supine	11 prone and 19 supine	MVCBCT	Off-line protocol	Inter	Bony anatomy	Larger residual setup error in supine position due to larger random errors (5.4 vs 5.0 mm 3D vector length)
Greer et al. [39]	Prone vs supine and tattoo vs fixed height (AP direction only)	8 prone and 11 supine	Portal films	No	Inter	Bony anatomy	*Tattoo alignment:* larger mean deviation (5.2 vs 3.3 mm), random (3.3 vs 2.3 mm) and systematic position variation (4.5 vs 3.7 mm) in the prone vs supine position *Fixed height alignment:* no significant difference in mean deviation (0.1 vs 0.4 mm), random (1.2 vs 1.3 mm) and systematic position variation (1.1 vs 1.2 mm) in the prone vs supine position
Weber et al. [40]	Prone vs supine	12 prone and 10 supine	Portal films	No	Inter	Bony anatomy	No differences in average position deviation and random errors. Only systematic errors larger in the prone position (4.1 vs 2.2 mm) SI and (2.7 vs 1.9 mm) AP
Malone et al. [41]	Prone with and without immobilization and supine	20 patients in three different positions	Fluoroscopy + f.m.	n.a.	Intra (breathing)	Prostate	In immobilized prone patients the mean total displacement was 3.3 ± 1.8 (SD) mm. Larger breathing motion with immobilization in the SI and AP directions than without immobilization. No difference between supine and prone without immobilization
Dawson et al. [42]	Prone with 2 different immobilisation methods, supine with flat and false table	4 patients in four different positions	Fluoroscopy + f.m.	n.a.	Intra (breathing)	Prostate	Larger breathing motion in prone position especially with immobilisation devices. Breathing motion 0.9–5.1 mm SI and up to 3.5 mm AP in prone position, <0.1 mm in supine position
Kitamura et al. [43]	Prone and supine	10 patients in two different positions	Tumour tracking + f.m.	n.a.	Intra (breathing)	Prostate	Larger average amplitude of the internal prostate motion in prone position (0.5–1.6 mm) than in supine position (0.1–0.3 mm)
Bittner et al. [44]	Prone with immobilization comparison with supine results from Langen et al. [82]	17 patients prone with immobilisation	Calypso localisation system	n.a.	Intra	Prostate	Comparable intrafraction motion in prone (3D displacement ⩾ 3 mm and ⩾ 5 mm in 13.9% and 1.5% of time) and supine position (3D displacement ⩾ 3 mm and ⩾ 5 mm in 13.2% and 3.1% of time)
Shah et al. [50]	Prone and supine	20 patients both prone and supine	Calypso localisation system	n.a.	Intra	Prostate	The prostate was displaced > 3 and > 5 mm for 37.8% and 10.1% of the time in prone and for 12.6% and 2.9% of the time in supine position: mostly in the inferior and posterior direction. For larger displacements (>7 mm) no differences were observed
Wilder et al. [45]	Prone and supine	15 patients in two different positions	Pre and post treatment EPIs + f.m.	n.a.	Intra	Prostate	No significant difference in intrafraction movement between prone and supine (mean = 2 mm; 1 SD = 1.2–2.0 mm in AP and SI direction)
Vargas et al. [46]	Prone and supine with and without a rectal balloon (r.b.)	4 patients in four different combinations	Cine-MRI	n.a.	Intra	Prostate	The 3D intrafraction motion (SD) was 0.6 and 1.2 mm for the supine position with and without r.b. and 1.5 and 2.2 mm for the prone position with and without r.b.
Bayley et al. [47]	Supine and prone both with immobilisation	28 patients in two different positions	Lateral portal films + f.m. after on-line correction	On-line on bony anatomy action level 3 mm	Inter	Prostate	More on-line position corrections in prone position because of larger deviations bony anatomy. No significant differences in mean position deviation prostate: in AP direction 0.1 ± 3.3 (SD) mm supine vs 0.5 ± 2.5 mm prone and in SI direction 1.1 ± 3.8 mm supine vs 1.3 ± 4.6 mm prone
McLaughlin et al. [48]	Supine and two prone (flat and angled table) positions	10 patients in three different positions	CT-scans: pretreatment and after 5 weeks	n.a.	Inter	Prostate	No significant differences in prostate position observed: average c.o.m. shift 6.1 mm in supine and 6.2 mm in prone flat position

Table 3 (*continued*)

Paper	Patient position comparison	No. of patients	Method	Correction protocol used	Intra or interfraction motion	Setup error of	Results
Stroom et al. [52]	Supine and prone on a BB position	15 patients supine and 15 prone on a BB	One pre-treatment and three repeated CT-scans	n.a.	Inter	Prostate	Smaller random (σ = 1.7 mm AP and 1.5 mm SI) but larger systematic variations (Σ = 3.3 mm AP and 2.2 mm SI) in prone patients than supine patients (σ = 2.8 mm AP and 2.5 mm SI and Σ = 2.5 mm AP and 2.7 mm SI) resulting in similar PTV margins for the two treatment positions (1 cm AP and SI and 0.5 cm lateral). In supine position time trends caused a significant systematic ventral-superior shift
Liu et al. [49]	Supine and prone position	20 patients in supine or prone position	Ten repeated CT-scans	Different image guidance strategies	Inter	Bony anatomy and c.o.m. prostate	Using soft tissue alignment and 0.5 cm margins adequate CTV coverage both in prone and supine position. Worse CTV coverage with bony alignment; better CTV coverage for prone than for supine positions
Nijkamp et al. [51]	Supine comparison with prone results from Nijkamp et al. [83] both on a flat table	28 patients in supine and 27 in prone position	Five daily CBCT's	CBCT's before on-line correction	Inter	Rectum	Large systematic (1–8 mm (1SD)) and random (1–5 mm) shape variations of the mesorectum comparable to prone patients. Larger differences between male and female patients than between supine and prone positions. Proposed margins for the upper half of the mesorectum up to 1.7 and 2.3 cm for male and female patients in prone position and up to 1.9 and 2.4 cm for male and female patients in supine position

Abbreviations: AP, anterior posterior; CBCT, Conebeam-CT; SI, superior inferior; c.o.m., center of mass; EPI, Electronic Portal Images; f.m., fiducial marker; MVCBCT, Megavoltage Conebeam-CT; n.a., not applicable; r.b., rectal balloon; 3D, three-dimensional.

low dose areas is not known yet, they could though play a role in late induction of second cancers [2].

A full bladder, as a natural spacer, might also influence the irradiated SB-V. Two studies showed that a full bladder by itself reduces the SB-V in the treatment volume [28,29]. In many of the reviewed publications the bladder filling protocol used was not mentioned, which is an important limitation of these studies. Keeping the bladder filling constant is a challenge and can lead to significant changes of the bladder volume during an irradiation course [69–72]. Specific instructions for bladder filling/emptying help to minimise differences in bladder filling [71].

Therapeutical sequence

Postoperative the pelvic anatomy has changed, with consequently repositioning of the SB.

The question rises whether SB sparing still occurs in patients with previous surgery. One prospective study by Gallagher et al. [54] and three retrospective studies [55–57] observed a similar SB-V reduction in patients with and without previous surgery. Therefore, the gain of the use of a BB seems to persist in postoperatively irradiated patients. Kim et al. also found in their prospective studies a significant reduction of the irradiated SB-V by using a BB in both the pre- and postoperatively treated patient groups [28,29]. Furthermore, Capirci et al. [63] observed in a retrospective study a significantly higher mobilisation of SB loops prone on a BB compared to the prone position alone (17 vs 25%, $p < 0.05$) in 345 patients treated in an adjuvant setting. However, Fu et al. [59] found no advantage in the patient group with previous surgery.

So far, we have seen that the irradiated SB-V can be reduced by the use of a full bladder protocol, prone position and a belly board, both using 3D-CRT or IMRT, in pre- and postoperatively irradiated patients. The clinical relevance, on the other hand, depends on the complication risks which are related to the absolute amount of SB-V in the treated volume.

Clinical relevance of the irradiated SB-V

Acute small bowel toxicity

Baglan et al. [10] generated a threshold-type model of acute small bowel toxicity relating the SB-V receiving 15 Gy or less to the risk of developing grade III GI-toxicity. They found a strong relationship between the SB-V receiving at least 15 Gy and the degree of acute small bowel toxicity in a rectal cancer patient group receiving chemoradiation. Mainly grade 0–1 toxicity was seen after irradiation with a V15 of less than 150 cc (grade 0–I in 90%, grade 2 in 10% of the patients). However, 70% of the patients with a V15 of more than 300 cc experienced grade 3 toxicity.

The model of Baglan et al. was later validated by Robertson et al. [73]. They demonstrated that even reducing the areas of SB receiving a low dose can diminish the complication rate significantly (Baglan–Robertson threshold model) [8,10,73].

Roeske et al. found a significant correlation between the amount of SB receiving 45 Gy and acute grade III toxicity in their multivariate analysis (Roeske-threshold-model) [8,12]. This study population consisted of 50 gynaecological patients, who were treated with whole pelvis IMRT consisting of 45 Gy in fractions of 1.8 Gy. They fitted their data in a NTCP model. The risk of acute GI toxicity was 1.8% for SB-V of 100 cc receiving 45 Gy, while after irradiation of a 200 cc SB-V with a similar dose the risk was 9.9%.

The above mentioned authors found different thresholds, which might be explained by the differences in contouring of the SB. Roeske et al. contoured the entire potential space of small-bowel location (the peritoneal cavity) while Baglan et al. and Robertson et al. contoured the single SB-loops. Interestingly Gunnlaugsson et al. [74] compared in a small retrospective study with 20 patients different contouring methods and found a strong correlation between the occurrence of acute toxicity and the irradiated small bowel loops. No significant correlation could be demonstrated for the drawn ‘‘abdominal space’’. It is therefore recommended to contour the SB-loops instead of an ‘‘abdominal space’’.

That a reduction of SB-V effectively results in reduced gastrointestinal toxicity was confirmed in a retrospective study by Samuelian et al. [7]. Both grade 2 of higher diarrhea (7 vs 29 patients, $p = 0.02$) and enteritis (2 vs 18 patients, $p = 0.015$) were reduced in patients treated supine with IMRT as compared to prone on a BB with CRT. The overall gastrointestinal toxicity was reduced from 62% in the CRT-group to 32% in the IMRT-group ($p = 0.006$) [7]. This reduction of acute gastrointestinal toxicity correlated not only to the SB-V45 but also to the lower mean irradiation dose [7]. This clinical observation confirms the findings of the above described models and stresses the importance to continue to try to reduce also SB-V receiving low doses of irradiation.

Late small bowel toxicity

Reduction of the irradiated SB-V will also influence the late small bowel toxicity. In studies with a median follow-up of 16 months (10–24 months) and a minimal follow-up of 2 years, respectively, Gallagher et al. and Letschtert et al. confirmed a correlation of late bowel toxicity (chronic diarrhea and small bowel obstruction) with the irradiated SB-V and the dose given to the SB-V [54,75]. A remarkable increase of late toxicity was seen in SB-V irradiated with 45 Gy or more.

In conclusion, the clinical relevance of the gain of a BB depends on the absolute small bowel volume close to the target volumes instead of on treatment indications. For example, in preoperative rectal cancer radiotherapy, treating only the mesorectum and the internal iliacal nodes, the irradiated SB-V will generally remain below the threshold for toxicity. Depending on the chosen treatment schedule and the individual anatomy of a patient treated for a rectal cancer a BB can result in reduction of gastrointestinal toxicity through better sparing of the SB.

For postoperative cervical cancer, typically larger treatment volumes are contoured, including the obturator and often the iliac nodes. In patients treated for these indications the irradiated SB-V will in general be much larger. Therefore the gain of the use of a belly board is expected to be greater in the latter patient group. Fu et al. [59] found indeed in his analysis of 51 patients with gynaecological and gastroenterological pelvic malignancies a significant reduction of the SB-V only in gynaecological malignancies and not in rectal cancer. This study is not included in this review because the SB-V is evaluated with orthogonal radiographs instead of DVHs.

The position of the BB in relation to the irradiated volume is important to obtain a maximal SB-V reduction. The highest SB-V-reduction is seen placing the lower end of the BB-aperture at the lumbosacral joint which corresponds to an area close to the upper end of the PTV.

Patient set-up

Almost all papers that investigated the differences between the setup accuracy of the bony anatomy in supine and prone (with and without a BB) position found larger mean setup errors and systematic position variations in the prone position. It is questionable how relevant this is, since the mean setup error and systematic positioning errors can easily be corrected for by the use of off-line correction protocols like the no action level protocol (NAL) [76] or the shrinking action level protocol (SAL) [77]. With on-line correction protocols also the random interfraction setup errors can be corrected. There is no clear indication for larger residual setup errors of the bony anatomy for the prone position with or without a BB if position correction protocols are used.

The internal motion of the pelvic organs can be of the same order of magnitude as the setup errors of the bony anatomy [52,78–80]. For the prostate, the interfraction organ motion can easily be corrected for by using on-line correction protocols in combination with fiducial markers or soft tissue alignment. Therefore, the main question is whether the intrafraction internal motion depends on the patient position. Four papers described a larger [42,43,46,50] and two an equal intrafraction prostate motion [44,45] in prone compared to supine position. Therefore, no general conclusions can be drawn from these papers. Probably the results were influenced by the limited number of patients used in some studies and the differences in treatment protocols between the different institutes.

The PTV margins, required to account for setup errors and internal prostate motion, did not depend on the patient position. Margins of 0.5–1 cm in the AP and SI direction and 0.5 cm in the lateral direction were recommended [49,52].

For the rectum on-line correction protocols based on bony alignment can be used. However, still large (1.7–2.4 cm) PTV margins are required to account for the inter- and intrafraction shape variations of the mesorectum and other uncertainties in the procedures. Nijkamp et al. have shown that the required margins do not depend on patient position but do depend on gender [51].

Conclusions

The results of this review showed that a prone treatment position combined with a BB resulted in a lower irradiated SB-V as compared to the supine position or the prone position alone. This SB-V-reduction is seen in pre- and postoperatively irradiated patients, is valid for both 3D-CRT and IMRT treatment plans and might result in a reduced GI-morbidity. However the expected gain varies between patients. Therefore, the clinical relevance should be evaluated individually based on the absolute reduction of the SB-V in relation to the NTCP models. A full bladder helps to further reduce the SB-V; bladder filling instructions should be given. The patient position did not influence the required PTV margins for prostate and rectum. The highest SB-V-reduction is seen by placing the lower end of the BB-aperture around the upper end of the PTV.

Conflict of interest statement

The authors state that the research presented in this manuscript is free of conflicts of interest.

References

[1] Veldeman L, Madani I, Hulstaert F, De Meerleer G, Mareel M, De Neve W. Evidence behind use of intensity-modulated radiotherapy: a systematic review of comparative clinical studies. Lancet Oncol 2008;9:367–75.
[2] Guerrero Urbano MT, Nutting CM. Clinical use of intensity-modulated radiotherapy: Part II. Br J Radiol 2004;77:177–82.
[3] Purdy JA. Intensity-modulated radiotherapy: current status and issues of interest. Int J Radiat Oncol Biol Phys 2001;51:880–914.
[4] Wu QJ, Li T, Wu Q, Yin F. Adaptive radiation therapy: technical components and clinical applications. Cancer J 2011;17:182–9.
[5] Tanderup K, Georg D, Pötter R, Kirisits C, Grau C, Lindegaard JC. Adaptive management of cervical cancer radiotherapy. Semin Radiat Oncol 2010;20:121–9.
[6] Yoo DS, Wong TZ, Brizel DM. The role of adaptive and functional imaging modalities in radiation therapy: approach and application from a radiation oncology perspective. Semin Ultrasound CT MRI 2010;31:444–61.
[7] Samuelian JM, Callister MD, Ashman JB, Young-Fadok TM, Borad MJ, Gunderson LL. Reduced acute bowel toxicity in patients treated with intensity-modulated radiotherapy for rectal cancer. Int J Radiat Oncol Biol Phys 2011; doi:10.1016/j.ijrobp.2011.01.051.
[8] Kavanagh BD, Pan CC, Dawson LA, et al. Radiation dose–volume effects in the stomach and small bowel. Int J Radiat Oncol Biol Phys 2010;76:S101–7.
[9] Emami B, Lyman J, Brown A, et al. Tolerance of normal tissue to therapeutic irradiation. Int J Radiat Oncol Biol Phys 1991;21:109–22.
[10] Baglan KL, Frazier RC, Yan D, Huang RR, Martinez AA, Robertson JM. The dose–volume relationship of acute small bowel toxicity from concurrent 5-FU-based chemotherapy and radiation therapy for rectal cancer. Int J Radiat Oncol Biol Phys 2002;52:176–83.

[11] Roeske JC, Lujan A, Rotmensch J, Waggoner SE, Yamada D, Mundt AJ. Intensity-modulated whole pelvic radiation therapy in patients with gynecologic malignancies. Int J Radiat Oncol Biol Phys 2000;48:1613–21.
[12] Roeske JC, Bonta D, Mell LK, Lujan AE, Mundt AJ. A dosimetric analysis of acute gastrointestinal toxicity in women receiving intensity-modulated whole-pelvic radiation therapy. Radiother Oncol 2003;69:201–7.
[13] Minsky BD, Conti JA, Huang Y, Knopf K. Relationship of acute gastrointestinal toxicity and the volume of irradiated small bowel in patients receiving combined modality therapy for rectal cancer. J Clin Oncol 1995;13:1409–16.
[14] Lambrecht M, Deroose C, Roels S, et al. The use of FDG-PET/CT and diffusion-weighted magnetic resonance imaging for response prediction before, during and after preoperative chemoradiotherapy for rectal cancer. Acta Oncol 2010;49:956–63.
[15] van Stiphout RG, Lammering G, Buijsen J, et al. Development and external validation of a predictive model for pathological complete response of rectal cancer patients including sequential PET-CT imaging. Radiother Oncol 2011;98:126–33.
[16] O'Neill L, Armstrong J, Buckney S, Assiri M, Cannon M, Holmberg O. A phase II trial for the optimisation of treatment position in the radiation therapy of prostate cancer. Radiother Oncol 2008;88:61–6.
[17] Fiorino C, Valdagni R, Rancati T, Sanguineti G. Dose–volume effects for normal tissues in external radiotherapy: pelvis. Radiother Oncol 2009;93:153–67.
[18] Nijkamp J, Doodeman B, Marijnen C, Vincent A, van Vliet-Vroegindeweij C. Bowel exposure in rectal cancer IMRT using prone, supine, or a belly board. Radiother Oncol 2012;102:399–405.
[19] Drzymala M, Hawkins MA, Henrys AJ, Bedford J, Norman A, Tait DM. The effect of treatment position, prone or supine, on dose–volume histograms for pelvic radiotherapy in patients with rectal cancer. Br J Radiol 2009;82:321–7.
[20] Stromberger C, Kom Y, Kawgan-Kagan M, et al. Intensity-modulated radiotherapy in patients with cervical cancer. An intra-individual comparison of prone and supine positioning. Radiat Oncol 2010;5:63–8.
[21] Martin J, Fitzpatrick K, Horan G, et al. Treatment with a belly-board device significantly reduces the volume of small bowel irradiated and results in low acute toxicity in adjuvant radiotherapy for gynecologic cancer: results of a prospective study. Radiother Oncol 2005;74:267–74.
[22] Koelbl O, Richter S, Flentje M. Influence of patient positioning on dose–volume histogram and normal tissue complication probability for small bowel and bladder in patients receiving pelvic irradiation: a prospective study using a 3D planning system and a radiobiological model. Int J Radiat Oncol Biol Phys 1999;45:1193–8.
[23] Bertelrud K, Mehta M, Shanahan T, Utrie P, Gehring M. Bellyboard device reduces small bowel displacement. Radiol Technol 1991;62:284–7.
[24] Beriwal S, Jain SK, Heron DE, de Andrade RS, Lin CJ, Kim H. Dosimetric and toxicity comparison between prone and supine position IMRT for endometrial cancer. Int J Radiat Oncol Biol Phys 2007;67:485–9.
[25] Adli M, Mayr NA, Kaiser HS, et al. Does prone positioning reduce small bowel dose in pelvic radiation with intensity-modulated radiotherapy for gynecologic cancer? Int J Radiat Oncol Biol Phys 2003;57:230–8.
[26] Pinkawa M, Gagel B, Demirel C, Schmachtenberg A, Asadpour B, Eble MJ. Dose–volume histogram evaluation of prone and supine patient position in external beam radiotherapy for cervical and endometrial cancer. Radiother Oncol 2003;69:99–105.
[27] Kim JY, Kim DY, Kim TH, et al. Intensity-modulated radiotherapy with a belly board for rectal cancer. Int J Colorectal Dis 2007;22:373–9.
[28] Kim TH, Chie EK, Kim DY, et al. Comparison of the belly board device method and the distended bladder method for reducing irradiated small bowel volumes in preoperative radiotherapy of rectal cancer patients. Int J Radiat Oncol Biol Phys 2005;62:769–75.
[29] Kim TH, Kim DY, Cho KH, et al. Comparative analysis of the effects of belly board and bladder distension in postoperative radiotherapy of rectal cancer patients. Strahlenther Onkol 2005;9:601–5.
[30] Huh SJ, Park W, Ju SG, Lee JE, Han Y. Small-bowel displacement system for the sparing of small bowel in three-dimensional conformal radiotherapy for cervical cancer. Clin Oncol 2004;16:467–73.
[31] Das IJ, Lanciano RM, Movsas B, Kagawa K, Barnes SJ. Efficacy of a belly board device with CT-simulation in reducing small bowel volume within pelvic irradiation fields. Int J Radiat Oncol Biol Phys 1997;39:67–76.
[32] Hollenhorst H, Schaffer M, Romano M, et al. Optimized radiation of pelvic volumes in the clinical setting by using a novel bellyboard with integrated gonadal shielding. Med Dosim 2004;29:173–8.
[33] Huh SJ, Kang MK, Han Y. Small bowel displacement system-assisted intensity-modulated radiotherapy for cervical cancer. Gynecol Oncol 2004; 93:400–6.
[34] Koelbl O, Vordermark D, Flentje M. The relationship between belly board position and patient anatomy and its influence on dose–volume histogram of small bowel for postoperative radiotherapy of rectal cancer. Radiother Oncol 2003;67:345–9.
[35] Lee SH, Kim TH, Kim DY, et al. The effect of belly board location in rectal cancer patients treated with preoperative radiotherapy. Clin Oncol 2006;18: 441–6.
[36] Italia C, Fiorino C, Ciocca M, et al. Quality control by portal film analysis in radiotherapy for prostate cancer: a comparison between two different institutions and treatment techniques. Tumori 1998;84:640–8.
[37] Allal AS, Bischof S, Nouet P. Impact of the "belly board" device on treatment reproducibility in preoperative radiotherapy for rectal cancer. Strahlenther Onkol 2002;178:259–62.
[38] Siddiqui F, Shi C, Papanikolaou N, Fuss M. Image-guidance protocol comparison: supine and prone set-up accuracy for pelvic radiation therapy. Acta Oncol 2008;47:1344–50.
[39] Greer PB, Mortensen TM, Jose CC. Comparison of two methods for anterior–posterior isocenter localization in pelvic radiotherapy using electronic portal imaging. Int J Radiat Oncol Biol Phys 1998;41:1193–9.
[40] Weber DC, Nouet P, Rouzaud M, Miralbell R. Patient positioning in prostate radiotherapy: is prone better than supine? Int J Radiat Oncol Biol Phys 2000;47:365–71.
[41] Malone S, Crook JM, Kendal WS, Zanto JS. Respiratory-induced prostate motion: quantification and characterization. Int J Radiat Oncol Biol Phys 2000;48:105–9.
[42] Dawson L, Litzenberg D, Brock K, et al. A comparison of ventilatory prostate movement in four treatment positions. Int J Radiat Oncol Biol Phys 2000;48:319–23.
[43] Kitamura K, Shirato H, Seppenwoolde Y, et al. Three-dimensional intrafractional movement of prostate measured during real-time tumor-tracking radiotherapy in supine and prone treatment positions. Int J Radiat Oncol Biol Phys 2002;53:1117–23.
[44] Bittner N, Butler WM, Reed JL, et al. Electromagnetic tracking of intrafraction prostate displacement in patients externally immobilized in the prone position. Int J Radiat Oncol Biol Phys 2010;77:490–5.
[45] Wilder RB, Chittenden L, Mesa AV, et al. A prospective study of intrafraction prostate motion in the prone vs. supine position. Int J Radiat Oncol Biol Phys 2010;77:165–70.
[46] Vargas C, Saito AI, Hsi WC, et al. Cine-magnetic resonance imaging assessment of intrafraction motion for prostate cancer patients supine or prone with and without a rectal balloon. Am J Clin Oncol 2010;33:11–6.
[47] Bayley AJ, Catton CN, Haycocks T, et al. A randomized trial of supine vs. prone positioning in patients undergoing escalated dose conformal radiotherapy for prostate cancer. Radiother Oncol 2004;70:37–44.
[48] McLaughlin PW, Wygoda A, Sahijdak W, et al. The effect of patient position and treatment technique in conformal treatment of prostate cancer. Int J Radiat Oncol Biol Phys 1999;45:407–13.
[49] Liu B, Lerma FA, Patel S, et al. Dosimetric effects of the prone and supine positions on image guided localized prostate cancer radiotherapy. Radiother Oncol 2008;88:67–76.
[50] Shah AP, Kupelian PA, Willoughby TR, Langen KM, Meeks SL. An evaluation of intrafraction motion of the prostate in the prone and supine positions using electromagnetic tracking. Radiother Oncol 2011;99:37–43.
[51] Nijkamp J, de Jong R, Sonke JJ, van Vliet C, Marijnen C. Target volume shape variation during irradiation of rectal cancer patients in supine position: comparison with prone position. Radiother Oncol 2009;93:285–92.
[52] Stroom JC, Koper PCM, Korevaar GA, et al. Internal organ motion in prostate cancer patients treated in prone and supine treatment position. Radiother Oncol 1999;51:237–48.
[53] Caspers RJ, Hop WC. Irradiation of true pelvis for bladder and prostatic carcinoma in supine, prone or Trendelenburg position. Int J Radiat Oncol Biol Phys 1983;9:589–93.
[54] Gallagher MJ, Brereton HD, Rostock RA, et al. A prospective study of treatment techniques to minimize the volume of pelvic small bowel with reduction of acute and late effects associated with pelvic irradiation. Int J Radiat Oncol Biol Phys 1986;12:1565–73.
[55] Green N, Iba G, Smith WR. Measures to minimize small intestine injury in the irradiated pelvis. Cancer 1975;35:1633–40.
[56] Saynak M, Kucucuk S, Aslay I. Abdominal pillow for the sparing of small bowel in four-field conventional pelvic radiotherapy. Eur J Gynaecol Oncol 2008;29:643–8.
[57] Schraub S, Monnier A, Poulin G. Prevention of late complications in the small intestine by irradiation in Trendelenburg's position (author's transl.). J Radiol Electrol Med Nucl 1978;59:347–52.
[58] Weiss E, Richter S, Hess CF. Radiation therapy of the pelvic and paraaortic lymph nodes in cervical carcinoma: a prospective three-dimensional analysis of patient positioning and treatment technique. Radiother Oncol 2003;68:41–9.
[59] Fu YT, Lam JC, Tze JM. Measurement of irradiated small bowel volume in pelvic irradiation and the effect of a bellyboard. Clin Oncol (R Coll Radiol) 1995;7:188–92.
[60] Olofsen-van AM, Van den BH, Quint S, et al. Reduction of irradiated small bowel volume and accurate patient positioning by use of a bellyboard device in pelvic radiotherapy of gynecological cancer patients. Radiother Oncol 2001;59:87–93.
[61] Rudat V, Flentje M, Engenhart R, Metzger M, Wannenmacher M. The belly-board technic for the sparing of the small intestine. Studies on positioning accuracy taking into consideration conformational irradiation technics. Strahlenther Onkol 1995;171:437–43.
[62] Mak AC, Rich TA, Schultheiss TE, Kavanagh B, Ota DM, Romsdahl MM. Late complications of postoperative radiation therapy for cancer of the rectum and rectosigmoid. Int J Radiat Oncol Biol Phys 1994;28:597–603.
[63] Capirci C, Polico C, Mandoliti G. Dislocation of small bowel volume within box pelvic treatment fields, using new "up down table" device. Int J Radiat Oncol Biol Phys 2001;51:465–73.
[64] Ghosh K, Padilla LA, Murray KP, Downs LS, Carson LF, Dusenbery KE. Using a belly board device to reduce the small bowel volume within pelvic radiation fields in women with postoperatively treated cervical carcinoma. Gynecol Oncol 2001;83:271–5.

[65] Huh SJ, Lim DH, Ahn YC, et al. Effect of customized small bowel displacement system in pelvic irradiation. Int J Radiat Oncol Biol Phys 1998;40:623–7.
[66] Holst R, La CT, Koprowski C, Goldschmidt E. A simple manual method of repositioning small bowel during pelvic irradiation. Med Dosim 1995;20:123–9.
[67] Portelance L, Chao KS, Grigsby PW, Bennet H, Low D. Intensity-modulated radiation therapy (IMRT) reduces small bowel, rectum, and bladder doses in patients with cervical cancer receiving pelvic and para-aortic irradiation. Int J Radiat Oncol Biol Phys 2001;51:261–6.
[68] Mundt AJ, Roeske JC, Lujan AE, et al. Initial clinical experience with intensity-modulated whole-pelvis radiation therapy in women with gynecologic malignancies. Gynecol Oncol 2001;82:456–63.
[69] Button MR, Staffurth JN. Clinical application of image-guided radiotherapy in bladder and prostate cancer. Clin Oncol 2010;22:698–706.
[70] Pos F, Remeijer P. Adaptive management of bladder cancer radiotherapy. Semin Radiat Oncol 2010;20:116–20.
[71] Rosewall T, Catton C, Currie G, et al. The relationship between external beam radiotherapy dose and chronic urinary dysfunction – a methodological critique. Radiother Oncol 2010;97:40–7.
[72] Viswanathan AN, Yorke ED, Marks LB, Eifel PJ, Shipley WU. Radiation dose–volume effects of the urinary bladder. Int J Radiat Oncol Biol Phys 2010;76:S116–22.
[73] Robertson JM, Lockman D, Yan D, Wallace M. The dose–volume relationship of small bowel irradiation and acute grade 3 diarrhea during chemoradiotherapy for rectal cancer. Int J Radiat Oncol Biol Phys 2008;70:413–8.
[74] Gunnlaugsson A, Kjellen E, Nilsson P, Bendahl PO, Willner J, Johnsson A. Dose–volume relationships between enteritis and irradiated bowel volumes during 5-fluorouracil and oxaliplatin based chemoradiotherapy in locally advanced rectal cancer. Acta Oncol 2007;46:937–44.
[75] Letschert JGJ, Lebesque JV, De Boer RW, Hart AAM, Bartelink H. Dose–volume correlation in radiation-related late small-bowel complications: a clinical study. Radiother Oncol 1990;18:307–20.
[76] de Boer HCJ, Heijmen BJM. ENAL: an extension of the NAL setup correction protocol for effective use of weekly follow-up measurements. Int J Radiat Oncol Biol Phys 2007;67:1586–95.
[77] Bel A, Vos PH, Rodrigus PTR, et al. High-precision prostate cancer irradiation by clinical applicatio of an offline patient setup verification procedure, using portal imaging. Int J Radiat Oncol Biol Phys 1996;35:321–32.
[78] Ippolito E, Mertens I, Haustermans K, Gambacorta MA, Pasini D, Valentini V. IGRT in rectal cancer. Acta Oncol 2008;47:1317–24.
[79] Kaatee RSJP, Olosfsen MJJ, Verstraate MBJ, Quint S, Heijmen BJM. Detection of organ movement in cervix cancer patients using a fluoroscopic electronic portal imaging device and radiopaque markers. Int J Radiat Oncol Biol Phys 2002;54:576–83.
[80] Lim K, Kelly V, Stewart J, et al. Pelvic radiotherapy for cancer of the cervix: is what you plan actually what you deliver? Int J Radiat Oncol Biol Phys 2009;74:304–12.
[81] Shanahan TG, Mehta MP, Bertelrud KL, et al. Minimization of small bowel volume within treatment fields utilizing customized "belly boards". Int J Radiat Oncol Biol Phys 1990;19:469–76.
[82] Langen KM, Willoughby TR, Meeks SL, et al. Observations on real-time prostate gland motion using electromagnetic tracking. Int J Radiat Oncol Biol Phys 2008;71:1084–90.
[83] Nijkamp J, de Jong R, Sonke J, Remeijer P, van Vliet C, Marijnen C. Target volume shape variation during hypo-fractionated preoperative irradiation of rectal cancer patients. Radiother Oncol 2009;92:202–9.